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Tenth day of November 2003

J. K. H.

JANENE PEISKER
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AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Applicant(s):

SPATIAL FREEDOM HOLDINGS PTY LTD

A.C.N. 100 627 343

Invention Title:

THREE-DIMENSIONAL FORCE AND TORQUE CONVERTER

The invention is described in the following statement:

The present invention relates to control devices and more particularly is concerned with such devices which respond to input forces or torques in three dimensions and permit a control signal to be derived for controlling a machine such as a computer controlled system or the like.

The present inventor is also an inventor of inventions relating to three dimensional force and torque sensing devices which are the subject of US patents 4,811,608; 5,222,400; 5,706,027 and 5,798,748.

A further prior published proposal in the field is US 4,589,810 Heindl et al.

In recognising this other prior published material, the inventor does not admit that any of these other proposals are necessarily known to persons working in the field or of that of common general knowledge in any particular country.

The inventors prior patent number 4,811,608 discloses a six arm device where the arms are orthogonally arranged and responses in the arms to force or torque with respect to any axis in three dimensions are monitored using sensors.

The inventor has now appreciated that new and useful alternatives to his own prior art and other prior art items disclosed above would be highly advantageous and the present invention is concerned with such alternatives.

In summary the invention may be defined as a controller having four and only four arms extending from a body portion which is adapted to support the device, the arms being spaced from one another in three dimensions and the device having six or more degrees of constraint, tip portions of each of the arms engaging in connection means providing restricted relative motion, the connection means being attached to a gripping means which can apply force and/or torque in a three dimensional sense, the device including response detection means for monitoring responses in at least three of the four arms to provide an output signal representative of force and/or torque

applied through the gripping means whereby the device may control a system with the signal.

Preferably the arms are arranged in a tetrahedron shaped envelope and most preferably are almost equally spaced from one another in a symmetrical sense with included angles of approximately 105°. However a small degree of non-symmetry is preferred to ensure there is some preloading mechanically which addresses friction issues yet provides a device in which the computer based system can rapidly perform the relevant calculations that derive an accurate output signal.

Most preferably the arms are constrained such that the device has eight degrees of constraint.

Most preferably this is achieved by the tip of each arm having a ball element which is slidable along a cylindrical bore associated with the connection means and rotatable within reasonable limits inside the bore. Thus each such connection has freedom to engage in translational movement along the axis of the bore and limited freedom to rotate. The ball joint is thus constrained in two directions defining a plane at right angles to the axis of the bore and there are four dimensions of freedom in total and two constraints at each joint.

A preferred embodiment of the invention is one in which the sensors for monitoring response in the arms are disposed around a circular path in a plane. Preferably the sensing is an optical system.

The optical system can detect very accurately extremely small deflections in the arms responsive to the applied force or torque.

A preferred embodiment is one in which six sensors are provided in an array so that displacements in an X-Y set of directions for each of the four arms is achieved giving eight readings which can be resolved to give the required output signal.

By way of technical background, an explanation of

principles which may further explain the invention or some of its embodiments will be given, but the applicant is not to be bound by the completeness or correctness of this explanation. Further features of a preferred embodiments will also be explained.

The constraint relationship between two bodies can be determined by summing the constraints of the joint or joints between the two bodies excluding mechanisms which have special geometric alignments. A perfectly constrained device would have exactly six degrees of constraint. Perfectly constrained designs require high joint tolerances to avoid a rattling due to the joint clearances or to avoid excessive friction of the joints due to interference. In practice a slight interference renders the product unusable so perfectly constrained designs tend to exhibit a small amount of rattle due to the clearances in the joints. It is also desirable to provide a small amount of damping through some friction of the joints.

When a control device having a displaceable grip is designed, it is useful to recognise that when the grip is released damping avoids vibration issues and avoids the requirements of a very lightweight, grip as is the case with purely spring-based designs. The friction of a perfectly constrained design, when the grip is released, is only due to the weight of the grip and the frictional properties of the materials and hence is not adjustable in a typical design.

Overconstrained designs can be easily preloaded by slightly offsetting either side of a joint. Preferably only a small overconstraint is used to avoid tolerancing issues. A preferred embodiment of the present invention is slightly overconstrained with eight degrees of constraint. This allows the arms of the tube protrusions to be offset slightly relative to the connection means such as the cylindrical bores to introduce a slight preload when the device is at rest.

Durability of a design is impacted heavily by the wear characteristics of a joint. In perfectly constrained designs with point contact a small amount of wear increases the slop of the joint resulting in increased rattle of the device. The present preferred embodiments have line contact joints that wear much more slowly than point contact. In conjunction with a small preload the device does not exhibit slop.

The preferred embodiment has a central body and arms moulded as a single unit to form a tetra-star to provide rigid mounting of the arms of the body and to reduce cost. A complex tool is required to mould the central star part and each arm is formed by three sections of the tool. The preferred embodiment has spherical tips that engage with bores in an outer ball or shell which forms the grip. The mould has three parting lines. To avoid any flash from affecting the operation of the ball-in-hole joints, the ideal spherical surface is preferably cut back along the parting lines with a cylindrical surface so the flash will not touch the surface of the cylindrical bore associated with the outer bal.

In the preferred embodiment, there is an inner ball structure for mounting the tetra-star and comprising a lower and an upper section. Four holes in the inner ball are provided for the cylindrically bored extensions from the outer ball to pass through and engage the tetra-star's arms. These holes also limit the range of motion of the extensions and prevent the arms from being overstressed. Impact loads are passed directly from the extensions to the inner ball structure thereby avoiding damage of the tetra-star's arms so that a robust design is achieved.

Preferred embodiments use infrared LEDs and photodiodes to detect the tetra-star's arm displacements. Only six sets of sensors are required for the full 3D force and 3D torque computation. These are preferably arranged as three pairs with one arm having no sensors. Two pairs on two arms and the other two arms with a single

sensor is also possible but less desirable. Similarly eight sets of sensors could be used with a pair for each arm. Each arm would preferably have the optical axes perpendicular to each other.

In the preferred embodiment a shadow mask technology is used for sensing the displacement using an infrared LED and an infrared photodiode. The use of infrared provides greater immunity from ambient light affecting the measurement. Light falling on the photodiode from the LED generates a small current. As the arm deflects, the amount of light varies and in turn the amount of current varies. Greater linearity is achieved by keeping the voltage across the photodiode constant using an appropriate circuit. Each LED/photodiode pair has a characteristic loss factor measured as the ratio of the LED drive current vs. the photodiode output current with no shadow. This is typically around 200:1. For good accuracy the drive circuitry and/or computation needs to compensate for the variation in loss factor.

The preferred embodiment has ball-in-hole joints being 2 degree-of-constraint joints. These have line contact between the spherical ball-tip surface and the whole surface.

For exemplification only the invention will be described with reference to the following illustrative drawings:

Figure 1 is a three dimensional representation of a base unit of a three dimensional control device eg for controlling computers:

Figure 2 is a schematic vertical cross section through the device and having a generally spherical gripping cap for manual manipulation to operate the device;

Figure 3 is a three dimensional view of a tetra-star component used in the device; and

Figure 4 is a three dimensional representation from the interior of one of the segments of the cap of the

device and used for gripping purposes.

The principal components of the device comprise a tetra-star body 10 base, an inner bowl shaped cap 12 and an outer cap 13 formed from segments, one of which is shown in figure 4.

The tetra-star 10 has four arms 14 extending along respective axes from central body 15, the axes, being substantially uniformly geometrically disposed relative to one another. Each arm has an elongated reduced cross-section cylindrical portion 14A extending from a tapered base 16 and leading to a tip 17 having an enlarged head with, the surface profile including substantially a spherical portion 18 with a flattened end face 19. A series of structural webs 20 are individually formed on the tetra-star body.

The inner cap 12 has apertures 30 for accommodating tubular retainers 24 associated with the outer cap 13 and thereby limited displacement of the cap 13 (which acts as a grip).

As most clearly seen in figure 2 one of the arms extends substantially vertically upwards and, as described above, a preferred embodiment has optical sensing for detecting flexing in the arms. Figure 2 shows schematically a photo detector unit 21 having a light omitting diode (LED) 22 and photo detector 23. Each of the arms 14 is constrained with line contact in a respective tubular retainer 24 which is integrally formed with and projects inwardly from the respective cap segments of 13 to engage the tips 17.

The arrangement is such that the application of force or torque through the outer cap 13 with respect to any axes is detected by a characterising flexing in the arms. This flexing can be detected and computation determines the appropriate signal to be directed to a device such as a computer.

The invention which will be claimed will be any of the novel arrangement described herein either singly or in any combination and may include the following:

1. A controller having four and only four arms extending from a body portion which is adapted to support the device, the arms being spaced from one another in three dimensions and the device having six or more degrees of constraint, tip portions of each of the arms engaging in connection means providing restricted relative motion, the connection means being attached to a gripping means which can apply force and/or torque in a three dimensional sense, the device including response detection means for monitoring responses in each of the four arms to provide an output signal representative or force and/or torque applied through the gripping means, whereby the device may control a system with the signal.

2. A controller is described in clause 1 above and wherein the arms are arranged in a tetrahedron shaped envelope and are almost equally spaced from one another in a symmetrical sense with a small degree of non-symmetry to provide pre-loading at the connection means.

3. A controller is described in clause 1 or clause 2 and wherein the arms are constrained such that the device has eight degrees of constraint.

4. A controller as described in clause 3, wherein the tip of each arm has a portion with a part-spherical profile and is slidable along a cylindrical bore associated with the connection means and rotatable relative to the axis of the bore.

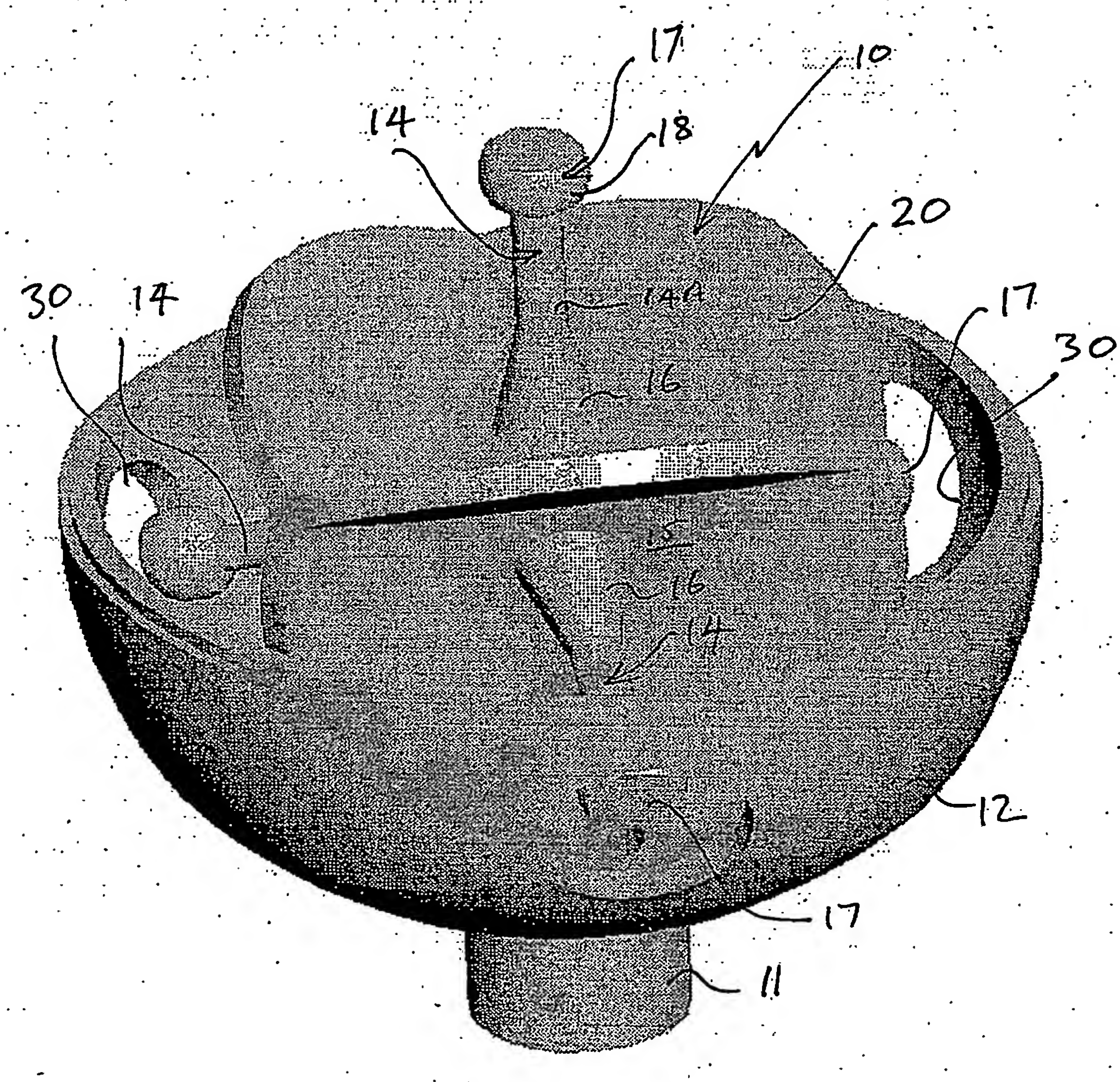

FIG 1

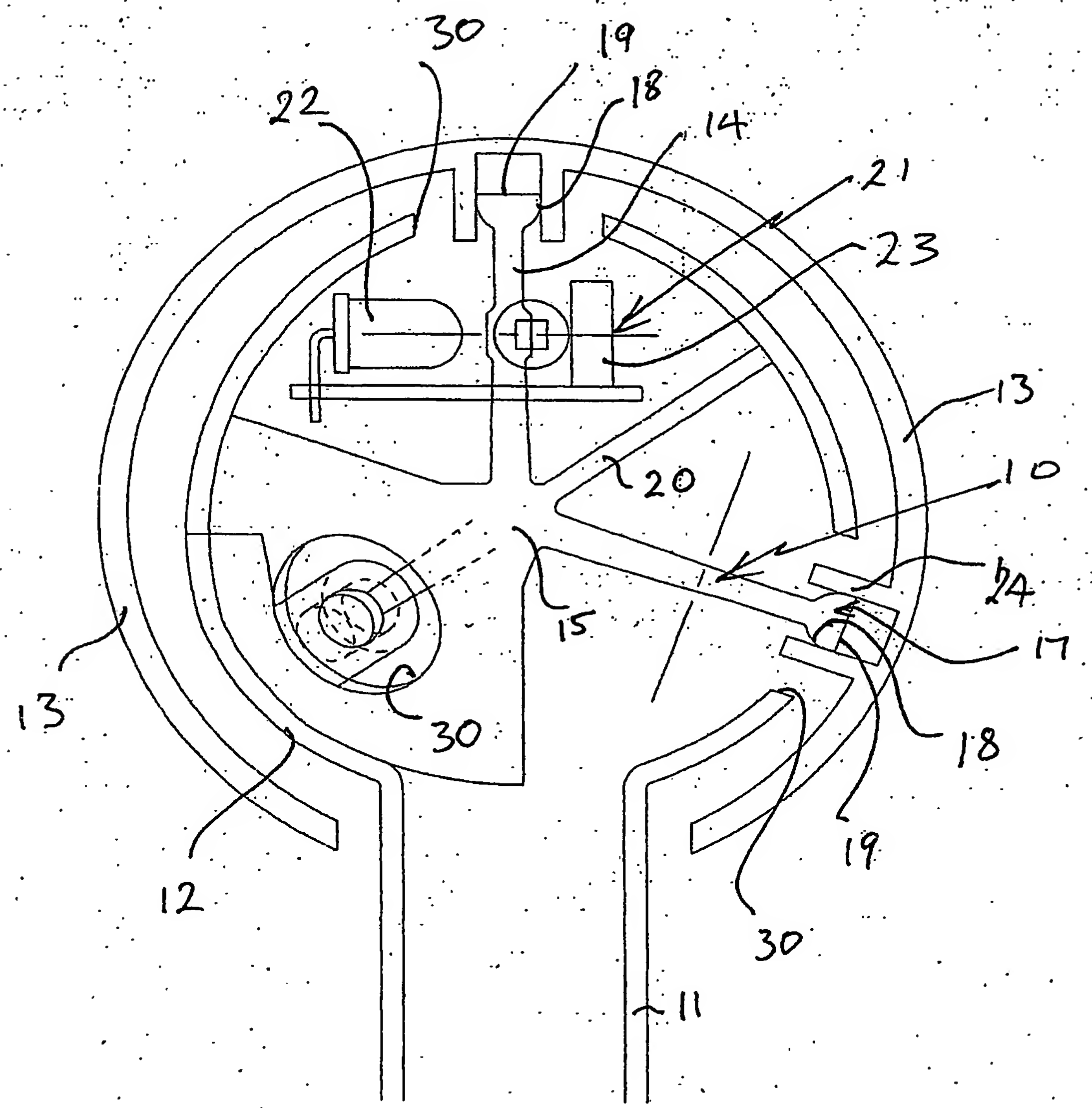

FIG 2

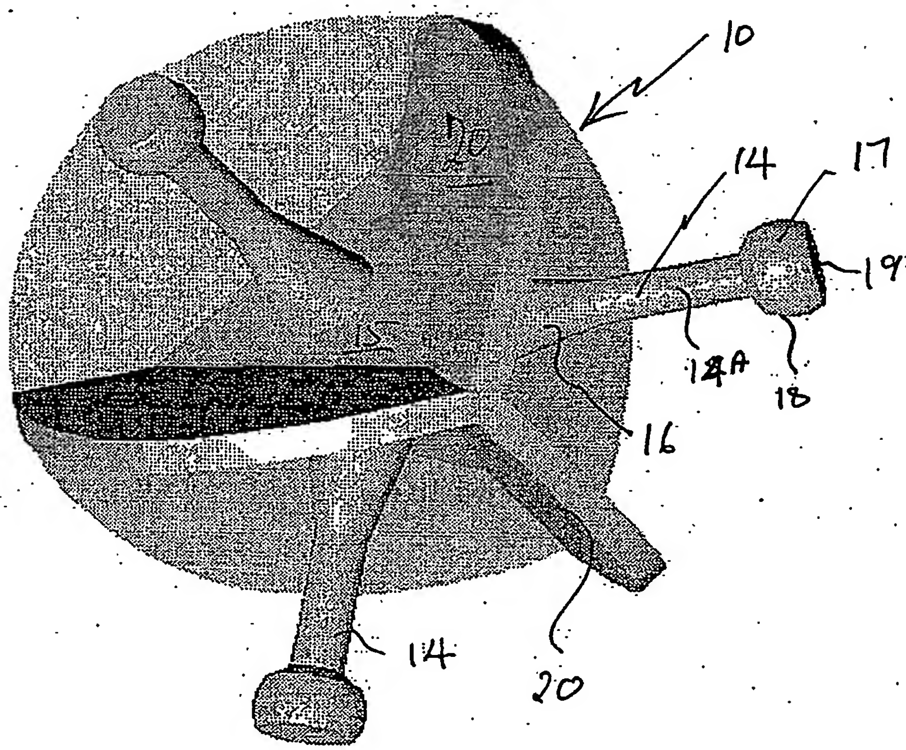

FIG 3

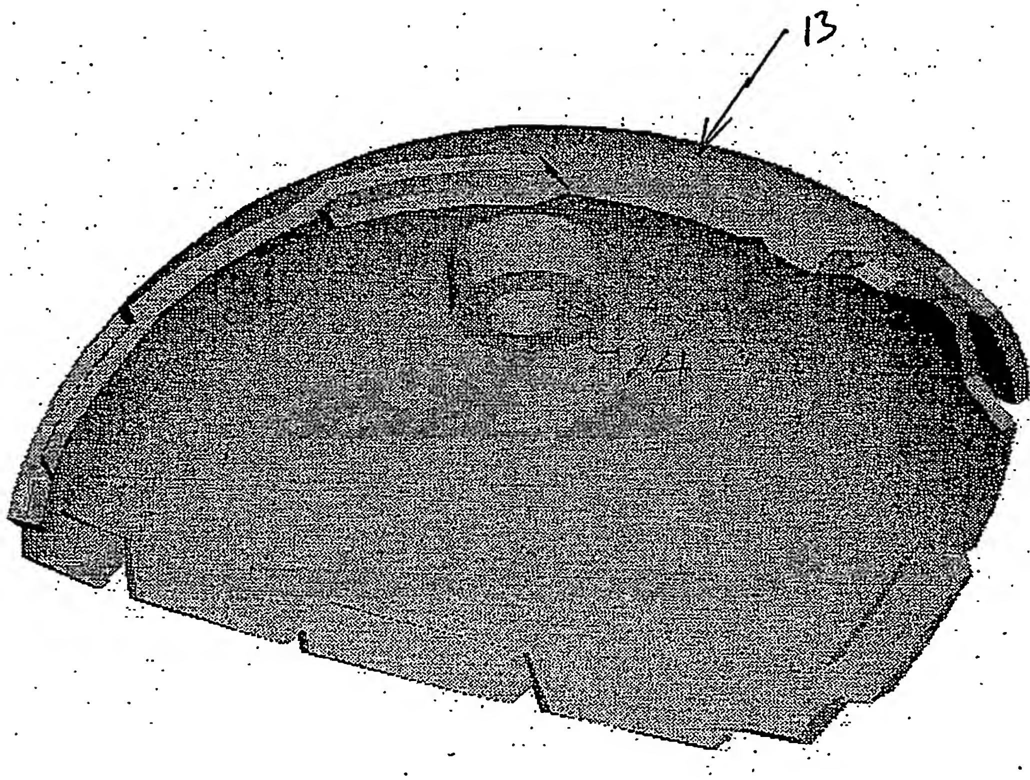

FIG 4